RELATIONSHIP OF SEGMENTAL ENERGY FLOW AND ELBOW VALGUS LOADING DURING BASEBALL PITCHING

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The purpose of this study was to examine the relationship of intersegmental power with elbow valgus load during pitching in adult baseball players. Kinematic and kinetic data from 24 male baseball pitchers (college n = 8; professional n = 16) were analysed using marker-based motion analysis and multiple linear regression. The segmental powers delivered by trunk rotation and shoulder internal rotation torques in the arm cocking phase accounted for 72% of the variance in peak elbow valgus torque (r = .848, p < 0.01). Furthermore, the power supplied by trunk rotation was the only significant predictor of ball speed (r = .840, p < 0.01). This segmental power analysis reinforces evidence that the rotational torques at the trunk and shoulder have the greatest effect on the development of elbow valgus load.

KEYWORDS: biomechanics; kinetics; mechanical energy; segmental motion

INTRODUCTION: Elbow injuries comprise a large proportion of injuries in professional baseball with pitchers being the most likely to sustain an elbow injury than any other position (Ciccotti et al., 2017). Because elbow injuries have been shown to be related to the biomechanical aspects of segmental motion during pitching, the kinematics and kinetics of each body segment rotating are relevant to the development of elbow valgus torque (Aguinaldo & Chambers, 2009).

Efficient throwing mechanics is predicated on a pitcher's ability to perform a sequence of movements in body segments in which the energy from the larger segments flows up the kinetic chain to the distal arm segments through the appropriate timing of the pelvis and trunk rotations in a manner that follows the summation of speed principle (Putnam, 1993). There is evidence that suggests that pitchers tend to generate more internal torque at the throwing arm to compensate for the energy dissipation due to poor sequential body motion, increasing injury risk (Aguinaldo & Chambers, 2009; Chu, Jayabalan, Kibler, & Press, 2016).

While previous studies have examined the relationship of energy flow and ball speed (Naito, Takagi, & Maruyama, 2011; Shimada, Ae, Fujii, Kawamura, & Takahashi, 2004), evidence on the mechanisms by which segmental energy transfer influences the development of elbow valgus loading is lacking. Therefore, the purpose of this study was to employ a segmental power analysis to examine the relationship between the flows of mechanical energy across body segments with elbow valgus loading during baseball pitching in adult players. Secondary aims of this study were to determine the influence of these segmental powers on ball speed as well as to identify the timing of maximal rotational velocities of pelvis, trunk, and shoulder during pitching. It was hypothesised that elbow valgus torque and ball speed would be most influenced by segmental powers supplied by trunk and shoulder rotations during the arm cocking phase of throwing. It was also hypothesised that pitchers would initiate trunk rotation earlier in the pitch cycle than what is considered optimal according to the summation of speed principle.

METHODS: Twenty-four male baseball pitchers recruited from the professional (n=16) and collegiate (n=8) ranks participated in this study after signing written informed consent forms approved by the university's Institutional Review Board. The mean ± SD age, height, weight, and body mass index (BMI) of the participants were 21.9 ± 3.7 years, 1.88 ± 0.06 m, 89.5 ± 9.0 kg, and 25.3 ± 2.0 kg/m^2, respectively. A set of 38 reflective markers (1.4 cm DIA) were placed on the skin overlying specific anatomical landmarks according to a 16-segment rigid-body model described by Aguinaldo and Chambers (2009). The marker set allowed for the estimation of 3-dimensional joint motion during throwing using an automated motion capture system of 8 near-infrared cameras (Raptor 4s; Motion Analysis Corp., Santa Rosa, CA) at a sampling rate of 300 Hz. The motion capture cameras were specifically positioned around an outdoor bullpen mound to allow for a 5 m (length) × 2 m (width) × 4.5 m (height) calibrated volume of space. Ball speed was recorded using a speed radar gun (Bushnell Performance Optics, Lenexa, Kansas) positioned behind the pitching mound.

Marker tracks were processed using marker identification techniques and digital signal processing that incorporated a fourth-order zero-lag Butterworth filter at a cut-off frequency of 18 Hz. The joint kinematics and kinetics of each participant's throwing motion were estimated based on the marker positions using a previously described link-segment model (Aguinaldo & Chambers, 2009). The flow of energy (power) between the trunk, upper arm, and forearm segments were calculated as the time rate-of-change in kinetic energy delivered into or out of each segment during pitching (Robertson & Winter, 1980). Each segmental power at any instant in time (i) was presumed to be equivalent to the sum of the powers (P_t) due to joint forces (F_j) and torques (T_j):

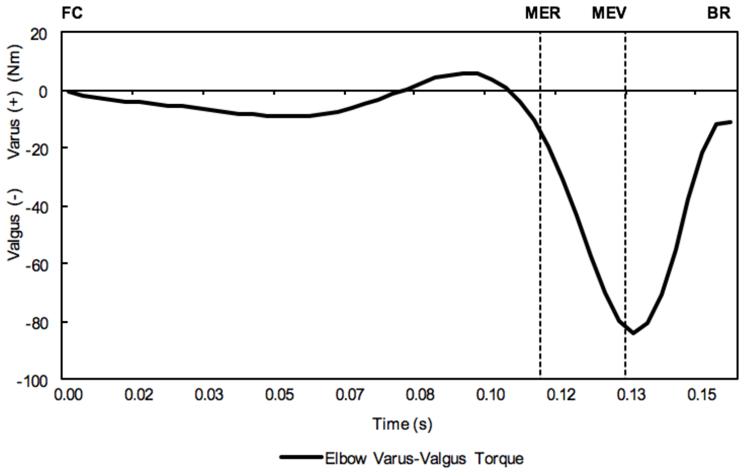
$$P_t(i) = \sum_{j=1}^{N} [T_j(i)\omega_j(i) + F_j(i)v_j(i)]$$

where N is the number of joints adjacent to a segment, ω_j is joint angular velocity about the segment's longitudinal axis (y) for the trunk and shoulder and medio-lateral axis for the elbow (x), and v_j is the linear velocity of the segment.

To assess the timing of segmental motion during the pitch, the time points in which the maximal magnitudes of pelvis rotation velocity, trunk rotation, trunk rotation velocity, elbow valgus torque, gleno-humeral external rotation, and internal rotation velocity of the throwing shoulder occurred during the pitching cycle (PC), normalized from front foot contact (FC) to ball release (BR), were also extracted.

Measurements of maximum elbow valgus (MEV) torque, ball speed, maximum trunk rotation time, and the peak magnitudes of the mechanical power of the trunk, upper arm, and forearm were extracted from each processed trial included in this sample and analysed for descriptive and correlational statistics. The extracted independent variables were entered into a multiple stepwise regression analysis to determine the linear model that best predicts MEV torque at a significance level of 0.05. As an index of pitching performance, ball speed was also evaluated to determine its relationship with these predictor variables using linear regression. A one-way repeated-measures analysis of variance (RM-ANOVA) was used to compare the timing of the maximum values of pelvis rotation velocity, trunk rotation, trunk rotation velocity, elbow valgus torque, external rotation, and internal rotation velocity of the throwing shoulder at an alpha level of 0.05. Post hoc pairwise comparisons were performed using a Bonferroni adjustment in the event of a significant main effect. All statistical analyses were performed using commercially available statistical software (SPSS Statistics v21; IBM Corp, Armonk, New York, USA).

RESULTS: The mean ± *SD* for MEV torque was 76.7 ± 27.6 Nm, occurring at the end of the arm cocking phase of the pitch at 80% ± 11% PC (Figure 1). The mean ± *SD* for the peak mechanical powers of the trunk, upper arm, and forearm segments were 3275 ± 1188 W, -1430 ± 657 W, and -2088 ± 849 W, respectively. The energy absorbed in the throwing arm segments paralleled the energy generated at the trunk during the arm cocking phase (Figure 1). The segmental powers of the trunk and upper arm in the arm cocking phase accounted for 71.9% of the variance in MEV torque ($r = 0.848$, $p < 0.001$) while trunk power was the only segmental power to significantly predict ball speed ($r = 0.840$, $p < 0.001$). The mean ± *SD* ball speed and pitching time were 36.9 ± 3.3 m/s and 0.21 ± 0.07 s, respectively. The timing in which the maximum values of relevant kinematic and kinetic events occurred during the pitching cycle was statistically different ($p < 0.001$) and are shown in Figure 2. However, the mean difference between the instants of maximum trunk rotation and maximum pelvis rotation velocity was not statistically significant ($p = 0.076$). Conversely, MER occurred significantly later in the pitching cycle than maximum trunk rotation velocity ($p < 0.001$).



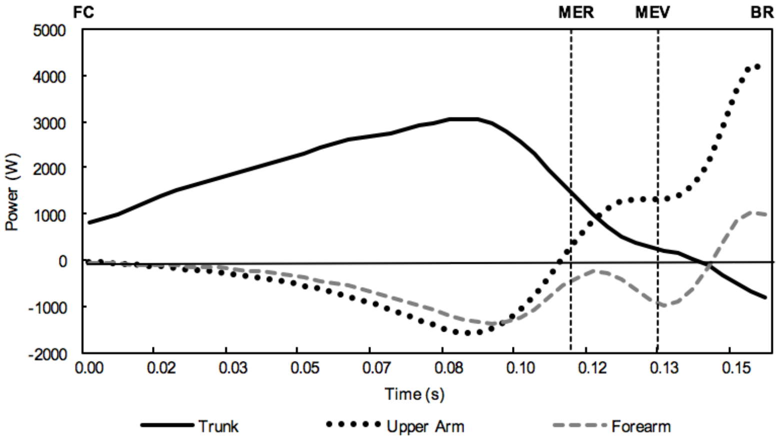


Figure 1: Elbow varus (+) / valgus (-) torque during a baseball pitch (top); Power histories of the trunk, upper arm, and forearm segments of the same pitch (bottom) (FC = front-foot contact, MER = maximum external rotation, MEV = maximum elbow valgus torque, BR = ball release).

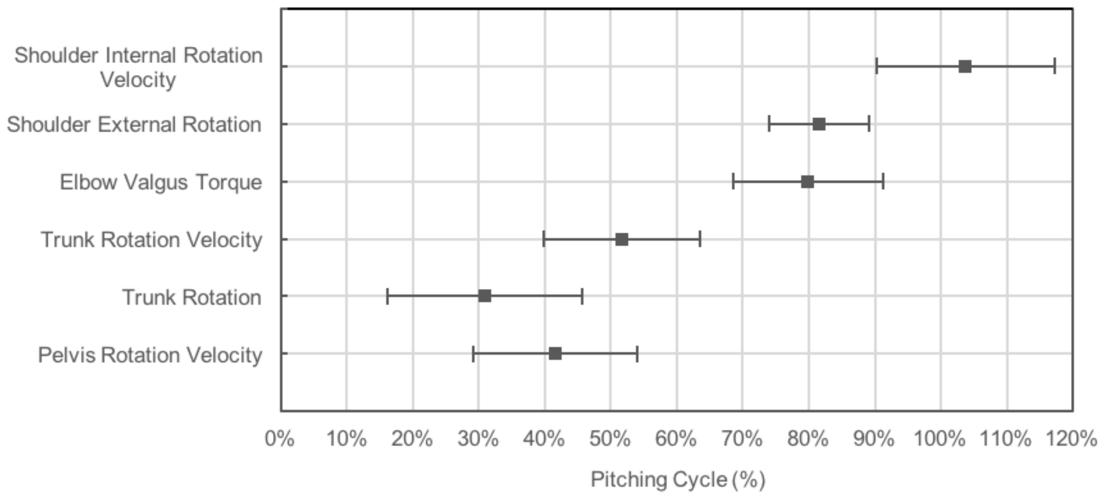


Figure 2. The mean ± *SD* timing of the maximum values of pelvis rotation velocity, trunk rotation, trunk rotation velocity, MEV torque, MER, and shoulder internal rotation velocity of the throwing arm during the pitching cycle, defined from FC (0%) to BR (100%).

DISCUSSION: As the mechanical efficiency of baseball pitching is predicated on the manner in which energy flows through each segment in the kinetic chain, the findings of this study have important implications relevant to injury prevention and performance in baseball pitching (Chu et al., 2016). While previous investigators have attempted to decompose these energy transfer mechanisms in relation to ball speed (Naito et al., 2011; Shimada et al., 2004), no study to date has examined how elbow valgus torque is influenced by energy flow using segmental power and regression analyses, which showed that the mechanical powers produced by the motions of the trunk and shoulder best predicted MEV torque. These results, therefore, support our primary hypothesis and reinforce the notion that the rotational torques at the trunk and shoulder during the arm cocking phase have the greatest effect on the development of elbow valgus loading (Aguinaldo & Chambers, 2009; Werner, Murray, Hawkins, & Gill, 2002). On the other hand, the results of this study showed that the power generated by trunk motion was the only significant predictor of ball speed, providing only partial support for the hypothesis that ball speed is most influenced by the powers of both the motions of the trunk and shoulder during the arm cocking phase. As trunk rotation occurred around the same time as peak pelvis angular velocity and internal rotation of the shoulder was initiated later in the pitching cycle, the energy generated at the larger segments transfers to the throwing arm segments in a sequential manner that closely follows the summation of speed principle (Naito et al., 2011; Shimada et al., 2004).

CONCLUSION: The peak mechanical powers of trunk and shoulder rotations during the arm cocking phase of baseball pitching significantly predicted maximum elbow valgus torque while the power of trunk rotation was the only energetic factor that significantly contributes to the variance in ball speed. These findings imply that the alterations of energy flow from the trunk to the throwing arm can play a predictive role in both injury and pitching performance.

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